# Implications of natural refrigerants for cooling technologies – Converting from HFCs/HCFCs to natural refrigerants

A guide for refrigeration manufacturers

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Friedrich-Ebert-Allee 36
53113 Bonn, Germany

E powering.agriculture@giz.de
I https://energypedia.info/wiki/Portal:Powering_Agriculture

GIZ Project Proklima
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

E proklima@giz.de
I www.giz.de/proklima

**Responsible:**
Bernhard Siegele, Proklima Programme Manager, bernhard.siegele@giz.de
Maria Weitz, Powering Agriculture Programme Manager, maria.weitz@giz.de

**Authors:**
Antoine Azar (HEAT GmbH), Ramona Nosbers (HEAT GmbH)

**Review and collaboration:**
Dr. Mischa Bechberger, Kerstin Lohr, Macben Makenzi, Katharina Meder, Robert Schultz,
Dr. Marcel Seyppel (GIZ Powering Agriculture)

Philipp Denzinger, Franziska Hartwig, Joana Kollert Cortez, Tobias Wagner (GIZ Proklima)

**Proofreading:**
Gunther Weinell (textschrittmacher)

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**On behalf of:**
German Federal Ministry for Economic Cooperation and Development (BMZ)
Division 410, Environment, sustainable use of natural resources, biodiversity, marine conservation, Ulrike Haupt
Division 121, Agriculture, Innovation, Agricultural Research, N.N.
Dahlmannstraße 4
53113 Bonn, Germany
T +49 228 99535-3520 (Ulrike Haupt), -2798 (Ref. 121)
F +49 228 99535-3500

E poststelle@bmz.bund.de
I www.bmz.de

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# Abstract

Especially in developing countries and emerging economies, the refrigeration and air conditioning (RAC) sector is expanding and is expected to account for 13% (GCI, 2014b) of global greenhouse gas (GHG) emissions by 2030, posing an ever-increasing environmental threat. HFCs, widely used to substitute CFCs and HCFCs under the Montreal Protocol (1989), have a global warming potential (GWP) of up to 4,000 times higher than $CO_2$. In addition, a majority of cooling appliances in use are not very energy efficient, consuming vast amounts of electricity and thereby indirectly contributing to GHG emissions that further accelerate climate change.

In the Kigali Amendment (2016) to the Montreal Protocol 197 countries have committed to phase down HFCs according to fixed schedules and baselines depending on their development status. The amendment is expected to hinder 90% of the temperature increase that would have been caused by HFCs. Its ratification in November 2017 heightens the pressure on manufacturers to produce climate-friendly RAC equipment.

This guide provides arguments and guidance for changing directly from HFCs to natural refrigerants in energy efficient systems, rather than focusing on intermediate HFC-substitutes (such as HFOs). Natural refrigerants are significantly less expensive compared to HFCs/HFOs, have negligible GWP and no ozone depleting potential (ODP), are infinite and their extraction from the atmosphere does not damage the environment. For almost every application and system type, refrigeration equipment using natural refrigerants is commercially available. Scientists, engineers and enterprises are constantly working on better and less costly ways and solutions to improve the safety of natural refrigerant systems along with energy efficiency measures.

When considering converting equipment to a new refrigerant, each system and related production must be evaluated independently to assess the uniform system design, installation location and production preconditions. Increased toxicity and/or flammability call for added attention when introducing natural refrigerants.

Meanwhile, natural refrigerants in general are technically and economically feasible alternatives to synthetic refrigerants for numerous applications. To support their timely introduction, barriers that currently slow down the wide-scale introduction of natural refrigerants, such as funding, standards and regulations, and adequate training, need to be addressed and solved.

This guide adresses in particular the manufacturers of commercial and industrial equipment. The aim is to:

- introduce international agreements and the regulatory landscape in key global regions (i.e. existing and upcoming F-gas policies),
- present availabe environmentally-friendly alternatives as direct replacement for HFCs and other chemical blends currently used in the refrigeration sector,
- provide information on relevant technical and economic aspects to be considered when converting to environment-friendly alternatives, e.g. for product redesign, new components and planning product line adaptations,
- provide practical application examples to demonstrate the technical feasibility of alternative technologies using natural refrigerants, conversion benefits and remaining challenges.

Finally, the recommendations intend to support manufacturers to be ahead of upcoming phase-out legislations, and to shorten their learning curve by providing, based on experiences, relevant information on potential technical and financial impacts when converting to natural refrigerants. This will allow RAC manufacturers to maintain their competitiveness in the global market and national governments to fulfil their commitments under the Kigali Amendment to the Montreal Protocol. Further, as HFCs are listed under the UN Framework Convention on Climate Change (UNFCCC) as GHG to be reported and reduced, the large-scale introduction of natural refrigerants also contributes to meeting the Paris Agreement's ambitious climate targets.

# Content

# Abbreviations

| | |
|---|---|
| AC | Air Conditioning |
| ATEX | Atmosphères Explosibles |
| CAPEX | Capital Expenditure |
| CFC | Chlorofluorocarbons |
| DOT | U.S. Department of Transport |
| EPA | U.S. Environmental Protection Agency |
| EU | European Union |
| F-gas | Fluorinated Gas |
| GCI | Green Cooling Initiative |
| GHG | Greenhouse Gas |
| GHGRP | Greenhouse Gas Reporting Program |
| GWP | Global Warming Potential |
| HC | Hydrocarbons |
| HCFC | Hydrochlorofluorocarbons |
| HFC | Hydrofluorocarbons |
| HFO | Hydrofluoroolefins |
| HPMP | HCFC Phase Out Management Plan |
| HVAC | Heating Ventilation and Air Conditioning |
| HX | Heat Exchanger |
| INDC | Intended Nationally Determined Contribution |
| IPCC | Intergovernmental Panel on Climate Change |
| LFL | Lower Flammable Limit |
| MP | Montreal Protocol |
| NDC | Nationally Determined Contribution |
| NGO | Non-governmental Organisation |
| NOU | National Ozone Unit |
| ODP | Ozone Depleting Potential |
| ODS | Ozone Depleting Substances |
| OPEX | Operational Expenditure |
| PAEGC | Powering Agriculture: An Energy Grand Challenge for Development |
| QRA | Quantitative Risk Assessment |
| RAC | Refrigeration and Air Conditioning |
| SDGs | Sustainable Development Goals |
| SEA | Swaziland Environment Authority |
| SOI | Sources of Ignition |
| TRS | Transport Refrigeration Systems |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WOT | Wire-on-tube |

# Glossary

**Coefficient of Performance (COP)** A measure of the energy efficiency of a refrigerating system, which is defined as the ratio between the refrigerating capacity and the power consumed by the system and primarily dependent on the working cycle and the temperature levels (evaporating/condensing temperature) as well as on the properties of the refrigerant, system design and size. The comparable term 'EER' or 'energy efficiency ratio' is also used.

**Global Warming Potential (GWP)** An index comparing the climate impact of a greenhouse gas relative to emitting the same amount of carbon dioxide. The GWP of carbon dioxide is standardised to 1. GWP includes the radiative efficiency, i.e. infrared-absorbing ability, of the gas as well as the rate at which it decays from the atmosphere. A GWP is calculated over a time interval of typically 20, 100 or 500 years.

**Hydrocarbon (HC)** Organic compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms. Hydrocarbons such as propane and isobutane have favourable thermodynamic properties for the use as refrigerants. They have no ozone depleting potential and very low global warming potential.

**Chlorofluorocarbon (CFC)** Chemical compounds that contain only chlorine and fluorine. Many CFCs have been widely used as refrigerants, foam blowing agents and solvents. They are potent greenhouse gases and harmful to the ozone layer. Consequentially, their manufacturing and use has been phased out by the Montreal Protocol.

**Hydrochlorofluorocarbon (HCFC)** HCFCs are halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. HCFCs act as potent greenhouse gases and deplete the ozone layer. They were used as intermediate replacements for CFCs, but they are being phased out by the Montreal Protocol and will be entirely banned as of 2030.

**Hydrofluorocarbons (HFC)** HFCs are halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine or iodine, they do not deplete the ozone layer, but like other halocarbons they are potent greenhouse gases. Consumption of HFCs is growing worldwide, due to their function as replacement substances for CFCs and HCFCs.

**Montreal Protocol (MP)** The Montreal Protocol on Substances that Deplete the Ozone Layer, effective since 1989 and signed by 197 countries, regulates the production and consumption of ODS. These include chlorine and bromine.

**Intended Nationally Determined Contributions (INDC)** Targets for reducing national GHG emissions, as communicated by parties responsible for over 90% of global emissions prior to the Paris climate negotiations in 2015.

**Nationally Determined Contributions (NDC)** Evaluations revealed that even the effect of the full implementation of all INDCs would not limit global warming to 2 °C. Consequentially, nations must update their INDCs and submit them as compulsory Nationally Determined Contributions (NDCs) by 2020.

**Ozone Depletion Potential (ODP)** A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by CFC-11. Specifically, the ODP of an ozone depleting substance (ODS) is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of CFC-11.

**Refrigerant** A fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid usually involving changes of the phase of the fluid.

# 1 Introduction

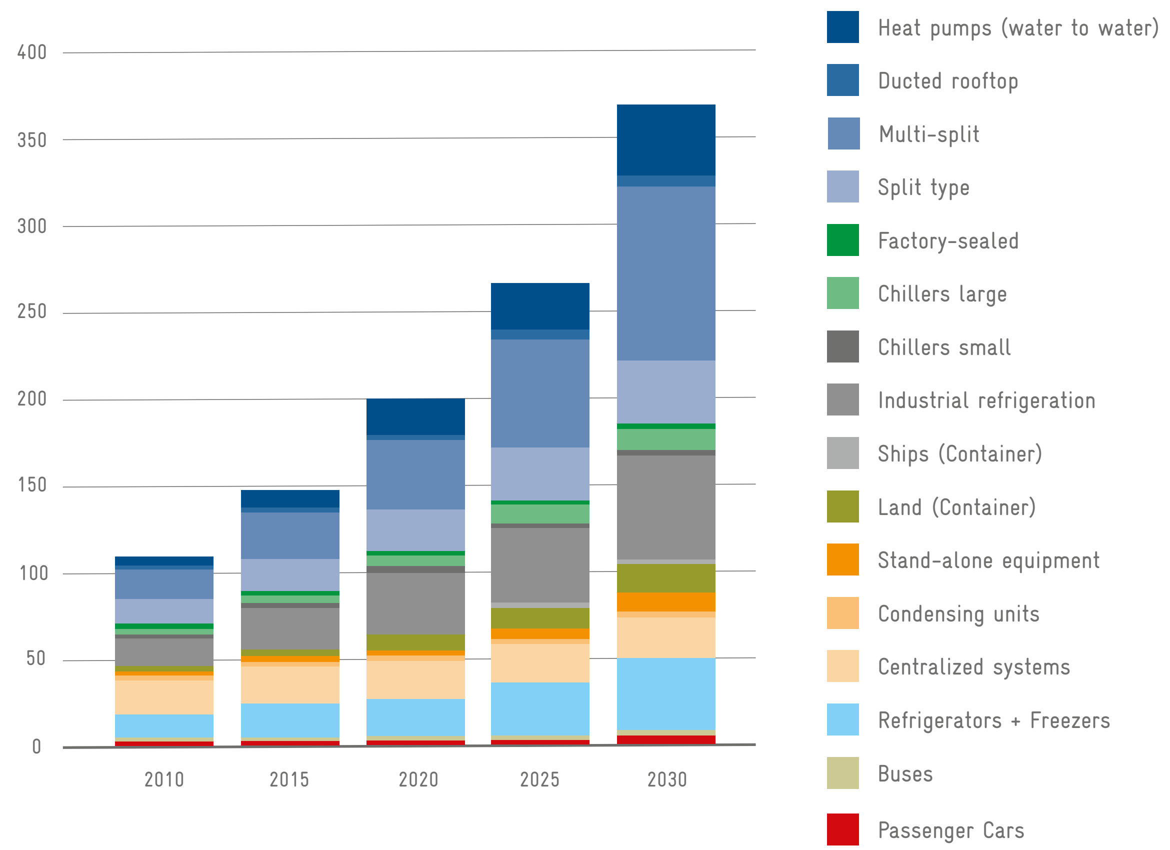


Figure 1: Global market volume of different applications for refrigeration and air conditioning in EUR billion (adapted and based on data from Schwarz et al., 2011)

A growing population, urbanisation, and an expanding middle class, especially in developing economies, is causing a vast market growth of diverse cooling appliances (Figure 1).

Increased usage of refrigeration and air conditioning (RAC) appliances leads to more greenhouse gas (GHG) emissions due to two reasons: indirect emissions from fossil fuel combustion for electricity generation, and direct emissions through the release of fluorinated gases used as refrigerants for cooling purposes. The Green Cooling Initiative (GCI) estimates that the RAC sector will account for 13% of the global GHG emissions by 2030, making this sector a rapidly increasing contributor to global warming.

Hydrofluorocarbons (HFCs) are being used as the main substitutes to phase out hydrochlorofluorocarbons (HCFCs) as ozone depleting substances under the Montreal Protocol (MP). HFCs are the fastest growing GHGs in many parts of the world, increasing by 10 to 15% annually (Velders et al., 2012), and they have an exceptionally high global warming potential (GWP). Figure 2 shows the $CO_2$eq emissions of clorofluorocarbons (CFCs), HCFCs and HFCs since 1950 and projects the trend to 2050. According to the UNEP report

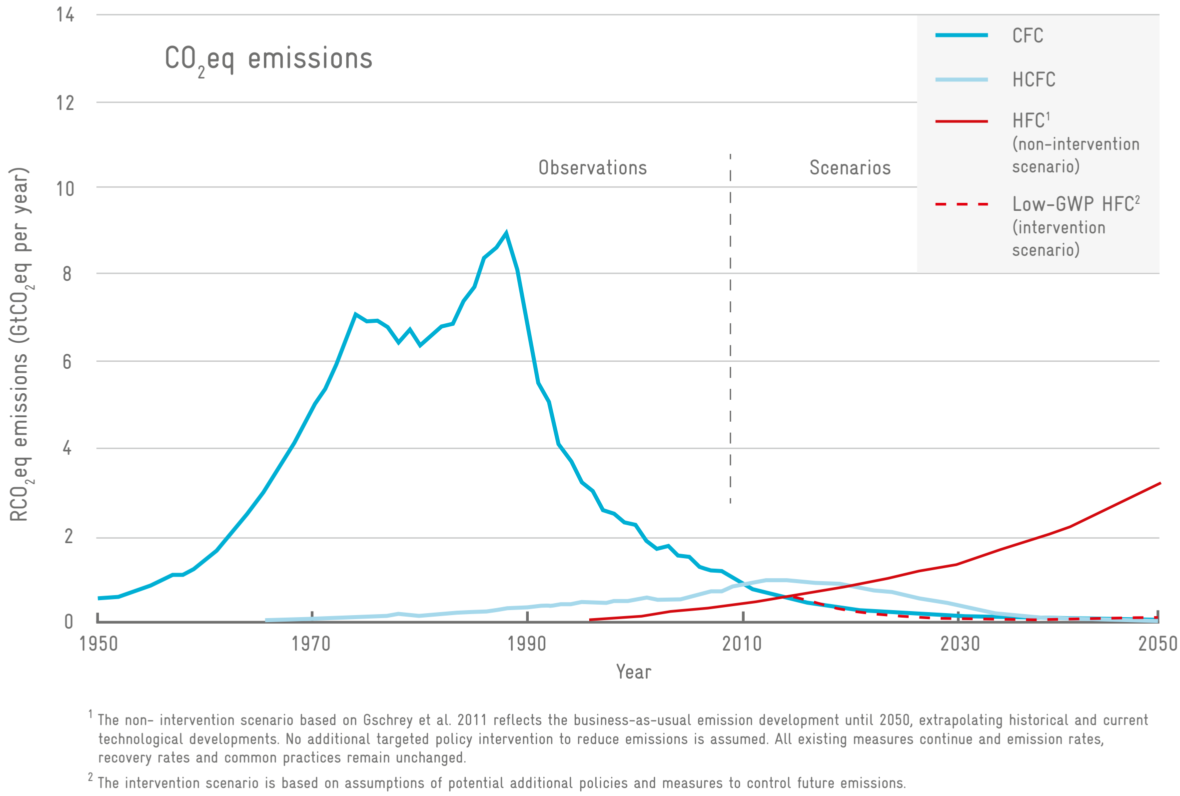


Figure 2: Trends in $CO_2$eq emission of CFCs, HCFCs and HFCs since 1950 and projected to 2050 (adapted from UNEP, 2011)

(National HFC inventories – 2016), if no measures are taken, it is estimated that HFCs will account for 9–19% of total $CO_2$eq emissions by 2050.

During the 28th Meeting of the Parties to the MP in October 2016 in Kigali, parties agreed to phase down HFC emissions over the next three decades, a significant contribution to achieving the objective to hold the increase in global average temperature well below 2 °C, set out in the Paris Agreement in 2015. The Kigali Amendment will avoid almost 90% of the temperature increase that HFCs could have caused (Velders et al., 2015).

In the past, the phase-out of one group of environmentally damaging refrigerants always led to substitution through lower ODP, but still, climate damaging refrigerants. This occurred in the switch from Chlorofluorocarbons to HCFCs, and on to HFCs in developed countries. Given the legal obligation set forward by the Kigali Amendment to phase out HFCs, it is conceivable that companies leapfrog directly from ozone depleting substances (ODS) to natural refrigerants in energy-efficient systems. This would avoid reliance on more expensive and energy-intensive HFC-substitutes which need to be phased out in the future anyway.

In order to introduce hydrocarbons and other natural refrigerants safely and successfully, it is essential for governmental institutions, the industry and, in particular, the relevant technicians to fully understand the issues related to their application. Technical matters, together with access to funding, further elevate manufacturers' concerns in making the switch.

The following guide will inform manufacturers of the regulatory landscape of refrigerant gases, present the alternatives (natural refrigerants) with their advantages and challenges, and elaborate on the technical and economical feasibilities with recommendations on how the HFC systems can be retrofitted/replaced easily and cost-effectively. Three case studies will be highlighted.

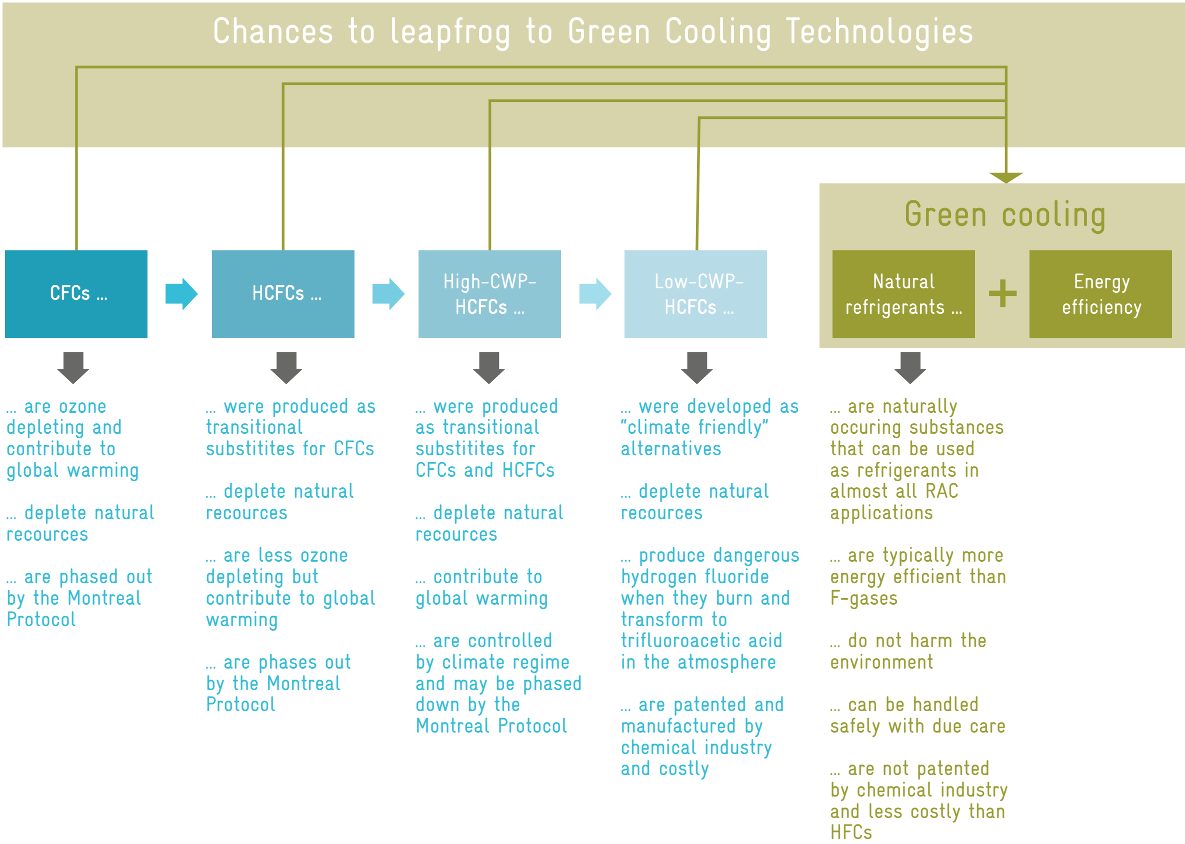


Figure 3: Leapfrogging to green technologies (adapted from GIZ GCI, 2014)

# 2 Policy Background – the development of F-gas regulations

Over the recent years, a policy framework surrounding F-gases has been developed to accommodate the heightened awareness of their global warming potential.

Numerous developing and developed countries have agreed to comply with international treaties, most importantly the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kigali Amendment to the Montreal Protocol, in order to coordinate international efforts against climate change. In addition, individual countries have taken it upon themselves to set regional and nation-wide regulations and sanctions on the consumption and production of F-gases.

## 2.1 The Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer, effective since 1989 and up to today signed by all 197 member parties of the United Nations (UN), regulates the production and consumption of ozone depleting substances. All the controlled substances contain either chlorine or bromine (UNEP, 2016).

Ozone depleting CFCs were phased out by 1996 and largely replaced by HCFCs. Whilst these have a lower ODP, they are still harmful to the ozone layer.

HCFCs are still widely used in developing countries but are currently phased down and replaced by HFCs. In developed countries, CFCs and HCFCs have been fully replaced by HFCs. Whilst HFCs are not classified as ODS, they still act as potent GHGs and thus contribute to rising global temperatures (EPA b, 2016).

### 2.1.1 The Kigali Amendment

In October 2016, the Parties to the Montreal Protocol adopted the Kigali Amendment, which adds the powerful greenhouse gases HFCs to the list of substances controlled under the Montreal Protocol (UNEP, 2016). Under the amendment, countries committed to cut the production and consumption of HFCs by more than 80% over the next 20–30 years. The timelines for the legally binding phase-down targets depend on the development status of the respective countries. Phase-down schedules will start in 2019 for developed countries and 2024 for developing countries.

The table below shows the phase-out timeline for different country groups.

The established phase-down schedule will avoid over 80 billion metric tons of $CO_2$ equivalent by 2050, hereby avoiding up to 0.5 °C warming by the end of the century and simultaneously protecting the ozone layer.

## 2.2 The Paris Agreement

While the Montreal Protocol successfully phased out ODS, it led to a shift towards HFCs. HFCs are GHGs that are considerably more potent than carbon dioxide in contributing to climate change. They are listed in Annex A to the Kyoto Protocol as gases to be reported and reduced.

The Paris Agreement under UNFCCC entered into force in November 2016 after 134 of the 197 UNFCCC Parties had signed it. Signatory parties have committed

| | Non-A5 (developed contries) | A5 (developed contries) Group 1 | A5 (developed contries) Group 2 |
|---|---|---|---|
| Baseline HFC component | 2011–2013 (average consumption) | 2020–2022 (average consumption) | 2024–2026 (average consumption) |
| Baseline HCFC component | 15% of baseline | 65% of baseline | 65% of baseline |
| Freeze | – | 2024 | 2028 |
| 1st step | 2019 – 10% | 2029 – 10% | 2032 – 10% |
| 2nd step | 2024 – 40% | 2035 – 30% | 2037 – 20% |
| 3rd step | 2029 – 70% | 2040 – 50% | 2042 – 30% |
| 4th step | 2034 – 80% | – | – |
| Plateau | 2036 – 85% | 2045 – 80% | 2047 – 85% |
| Notes | Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan, 25% HCFC component and 1st two steps later: 5% in 2020, 35% in 2025 | Article 5 countries not part of Group 2 | GCC (Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Bahrein, Oman), India, Iran, Iraq, Pakistan |

Table 1: HFC phase-down schedule under Kigali Amendment (adapted from and based on EPA, 2016)

to ‘holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels’.

Prior to the Paris climate negotiations in 2015, parties responsible for over 90% of global GHG emissions communicated targets for reducing national emissions in their Intended Nationally Determined Contributions (INDCs). Evaluations revealed that the collective effort, if all INDCs were to be fully implemented, will not suffice to limit the global temperature increase to 2 °C, let alone 1.5 °C. Consequentially, nations must act more ambitiously, with clear HFCs phase-out timelines, and in their commitments to limit global warming. They are now asked to review and update their INDCs and submit them as Nationally Determined Contributions (NDCs) by 2020.

## 2.3 F-gas policy in the European Union

Fluorinated gases (F-gases) account for 2% of the European Union’s (EU) overall GHG emissions, but F-gas emissions have risen by 60% since 1990 – in contrast to all other GHGs, which have been reduced (European Commission a, 2017). To control these emissions, the EU has adopted two legislative acts: the ‘MAC Directive’ (2008) on air conditioning systems used in small motor vehicles and the ‘F-gas Regulation’ (2006), which covers the remaining key applications of F-gases.

The MAC Directive prohibits the use of F-gases with a GWP higher than 150 times the GWP of $CO_2$ in small motor vehicles introduced from 2011, and for all new small motor vehicles produced from 2017.

The F-gas Regulation introduces two action pathways:

1. improving leak prevention, and
2. avoiding the use of F-gases where environmentally-friendlier alternatives are cost-effective.

In 2015 a new F-gas Regulation was introduced, which strengthened existing policies and introduced various far-reaching alterations, namely:

- limiting the total amount of potent F-gases that can be sold in the EU,
- phasing them down in steps, as shown in Figure 5, to one fifth of 2014 sales by 2030,
- banning the use of F-gases in any new types of equipment where more environmentally-friendly options are available, and
- preventing emissions of F-gases from existing appliances by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life.

As displayed in Figure 5, the EU's F-gas emissions will be cut by two thirds by 2030 compared to 2014 levels (European Commission b, 2017).

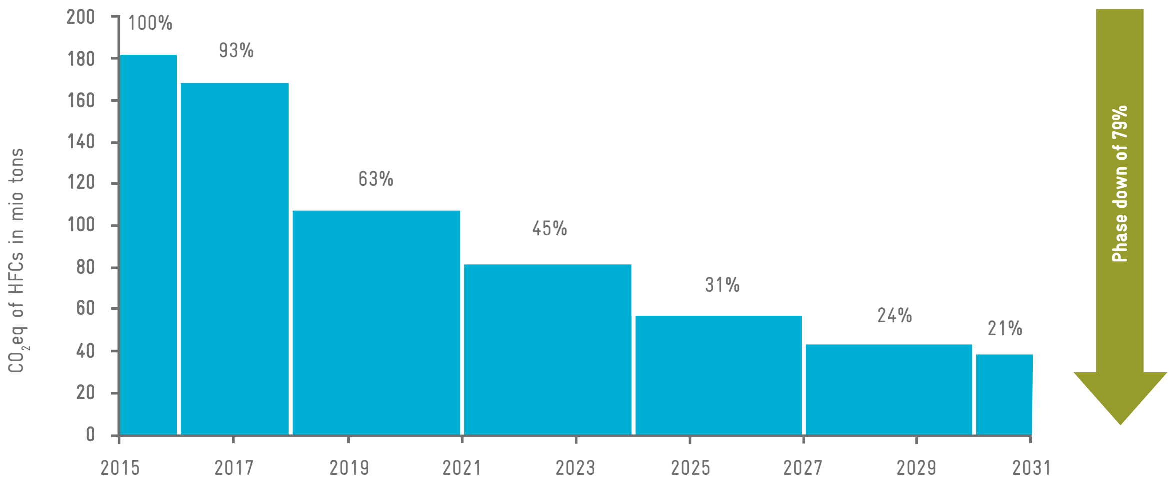


Figure 4: Development of HFCs in the EU market due to the F-Gas Regulation ($CO_2$ equivalent). Graph adapted, Data taken from the F-gas Regulation 517/2014 – Annex V

## 2.4 F-gas policy in Japan

In Japan, the revised F-Gas Regulation which entered into force in April 2015 focused on the reduction of F-gas emissions in the entire life cycle. This includes manufacturing, maintenance and leak checking, destruction and recycling, as well as the promotion of low-GWP/natural refrigerants in designated products.

Instead of imposing restrictions on the use of high-GWP refrigerants in certain applications (top-down approach), as in the EU F-Gas Regulation, the Japanese law sets quantitative GWP limits per product group, which each manufacturer must comply with (bottom-up approach). These targets are set for the sectors of highest environmental impact, where non-fluorinated refrigerants or other low-GWP substances exist. The new law includes four types of measures (Japan Ministry of the Environment, 2015):

- phase-down of HFCs,
- promotion of low-GWP products,
- prevention of leakage from commercial equipment,
- promotion of recycling.

## 2.5 F-gas policy in the USA

In 2009, the U.S. Environmental Protection Agency (EPA) developed the GHG Reporting Program (GHGRP), which requires the reporting of GHG data and other relevant information from large GHG emission sources. Since 2011, F-gases have also been included in the mandatory reporting scheme, with specific mention of HCFC-22, $CO_2$, $CH_4$ and $N_2O$. Furthermore, a F-gas Partnership Program was launched as a joint effort by EPA and industry groups to reduce the amount of F-gases emitted from various industrial processes. The programme promotes the development and adoption of cost-effective F-gas emission reduction opportunities. Past partnerships were held with the aluminium, magnesium and semiconductor industry. The current Electric Power Systems Partnership, established in 1999, is a collaborative effort between EPA and the electric power industry to identify, recommend, and implement cost-effective solutions to reduce sulphur hexafluoride SF6 emissions. The electric power industry uses roughly 80% of all SF6 produced worldwide (EPA a, 2016). Under the partnership, EPA shares information on best management practices and technical issues to help reducing emissions.

# 3 Conversion challenges in the refrigeration sector

Low-GWP alternatives for HFCs already exist on the market – natural refrigerants and Hydrofluoroolefins (HFOs). HFOs, the most recently introduced fluorinated refrigerants, have negligible GWP and pose no threat to the ozone layer. Yet, their production still relies on the mining and chemical extraction of fluorite and leads to environmental destruction. Despite the rapidly growing sales market for HFOs, producers and vendors continue selling the refrigerants at high prices. Natural refrigerants, including Hydrocarbons (HCs), such as propane or isobutane, carbon dioxide, ammonia, water and air, all occur naturally and have no or negligible GWPs and no ODP. Furthermore, their extraction from the atmosphere relies on standard processes and does not imply negative impacts on the environment. Due to their wide availability across the market for many different application areas they come at moderate prices.

The primarily used refrigerants for domestic refrigerators nowadays are the HFCs R134a and R600a, a natural refrigerant. Projections assume that about 75% of new domestic refrigerator production will use R600a by 2020 (UNEP, 2014).

R134a, one of the most commonly used HFCs, has a GWP of 1,300 considering a 100-year time horizon (IPCC, 2013; cf. Table 1). This implies that HFC-134a is 1,300 times more harmful to the climate with respect to global warming than $CO_2$. High-GWP refrigerants are listed as undesirable as of 1/1/2021 in the US (US Significant New Alternatives Policy – SNAP – programme listing) in domestic appliances and, due to the F-Gas Regulation (see section 2.3), they are even already prohibited for domestic refrigerators in the EU.

For light commercial applications, the mainly used refrigerants are the HFCs R134a and R404A, and the natural refrigerants R600a, R290 and $CO_2$. However, in many developing countries, the ozone depleting HCFC R22 is still in use.

For larger commercial applications, R404A is one of the major refrigerants in use. $CO_2$ is currently the most suitable natural refrigerant replacement.

In the EU, due to the F-Gas Regulation (cf. section 2.3), the limit of the GWP of the refrigerant used in hermetically sealed equipment for commercial cooling and freezing that is placed in the market will be 150 by 2022.

HCFCs, particularly R22, have already been phased out in the EU and the phase-out is close to being finalised in the US and other developed countries. Developing countries began phasing out HCFCs in 2015 and will continue until 2030.

| Refrigerants (common examples) | | ODP | GWP (time horizons of 100 years) |
|---|---|---|---|
| CFCs | R11 | 1 | 7,100 |
| HCFCs | R22 | 0.055 | 1,700 |
| HFCs | R507A | 0 | 3,985 |
| | R404A (R125+134a+143a) | 0 | 3,800 |
| | R410A (R32+135) | 0 | 2,000 |
| | R134a | 0 | 1,300 |
| HFOs | R1234yf | 0 | 6 |
| | R1234ze | 0 | 4 |
| Natural refrigerants | R290 (Propane) | 0 | 3 |
| | R600a (Isobutane) | 0 | 3 |
| | RC270 (Cyclopropane) | 0 | n/a |
| | R744 (Carbon dioxide) | 0 | 1 |
| | R717 (Ammonia) | | <1 |

Environmental impact

Fluorinated

Non-fluorinated

Table 2: ODP and GWP for commonly used refrigerants (Adapted from GIZ Proklima, based on data from IPCC, 2013)

## 3.1 Natural refrigerants

The three natural refrigerants currently in use are HCs, $CO_2$ and ammonia ($NH_3$). These refrigerants are classified in the international standards EN 378 and ISO 5149 as A3, A1 and B2, respectively. Figure 6 below clarifies these classifications, which are based on physical properties such as flammability and toxicity.

Increasing toxity →

| | No chronic toxicity effects below 400 ppm[1] | Chronic toxicity effects have been observed below 400 ppm |
|---|---|---|
| No flame propagation | A1 | B1 |
| Mild flammability | A2L | |
| Lower flammability | A2 | B2 |
| High flammability | A3 | B3 |

Increasing flammability ↓

Safety group

Figure 5: Safety classification according to ISO 817

1 Concentration by volume; ppm = parts per million.

### 3.1.1 Hydrocarbons[2]

Widely used HC refrigerants include propane (R290), isobutane (R600a), propylene (R1270) and mixtures thereof. They cover a wide range of cooling applications that include vending machines and coolers, commercial and industrial refrigeration units as well as air conditioning and chiller systems of all sizes. Technology is available to operate units and plants that use HC refrigerants under any common ambient condition and for a wide range of required cooling capacity. Due to the flammability of HCs in combination with oxygen, the maximum system size is defined by safety standards, such as e.g. EN 378 in Europe that limits the charge to 1–2.5 kg in occupied spaces. These national and regional safety standards are continuously revised in order to disseminate the technology and to benefit from its full potential.

On the technical level, it is favourable that most hydrocarbon refrigerants are compatible with standard oils and materials used with HFCs. The operating pressures of HCs are comparable to those of fluorocarbon refrigerants, such that the system design can be almost identical to that of synthetic refrigerants and only requires minor adjustments due to the flammability issue. Nevertheless, the potential for energy efficiency optimisation due to the specific thermodynamic specifications of HCs should be realised. Further, the comparatively low charges allow smaller piping dimensions and heat exchangers and thereby contribute to lower acquisition costs. Their very high critical temperatures and their ability to reject heat up to 50% faster than fluorocarbon refrigerants result in high energy efficiency for applications in high temperature environments. This makes HCs perfectly suited for applications in respective areas, e.g. the Middle East (Danfoss A/S a, 2017).

### 3.1.2 Ammonia[3]

Anhydrous Ammonia (R717) is a widely available natural refrigerant that demands certain safety measures due to its higher toxicity and lower flammability according to the rating in ISO 817 standards. It is particularly applicable in large industrial plants, where it often outperforms chemical refrigerants due to its favourable thermodynamic properties (Matt Cardin, 2011). On the other hand, due to safety reasons, its application in occupied spaces is limited. This problem can be circumvented by using indirect systems (two circuits where the ammonia circuit stays outside the occupied spacetrans, and via a heat exchanger, it transfers its energy to another coolant, i.e. glycol, which operates inside the occupied space) if it is economically reasonable (GIZ Proklima, 2008). Ammonia can be applied with standard oils that are also used with HFCs. Compared to HFC applications, smaller diameter piping can be used because of ammonia's high volumetric capacity, but potential cost savings are compensated by the need to use corrosion-proof welded steel tubings. Its reactivity with copper and brass further necessitates an open compressor design to prevent corrosion. This results in component prices which are 10 to 20% higher than for HFC systems. At the moment, most applications have high capacity charges. Efforts to construct low-charge ammonia systems are ongoing. They would have the potential to widen the field of applications for this highly efficient and environmentally-friendly refrigerant. Moreover, the use of ammonia as a refrigerant makes strict operational regulations obligatory, and requires appropriate training of technicians and a regular maintenance of systems (Danfoss A/S b, 2017).

### 3.1.3 Carbon dioxide[4] ($CO_2$)

$CO_2$ (R744) is rated with 'lower toxicity' and 'no flammability' by the ISO 817 standards. This permits the use of $CO_2$ as a refrigerant in most surroundings, without limitations to charge sizes. Yet, high working pressure levels in $CO_2$-systems and the low critical temperature introduce technical challenges. Constructive adjustments concerning the piping wall thickness, brazing methods, the materials used and certain key components, e.g. the compressor, become necessary. This applies particularly to systems with large internal volumes. Although these issues do not exceed technical

2 More information on hydrocarbons as refrigerant and their application can be found on http://www.hydrocarbons21.com

3 More information on ammonia as refrigerant and its application can be found on http://www.ammonia21.com

4 More information on carbon dioxide as refrigerant and its application can be found on http://www.r744.com

boundaries, they can lead to a certain upcharge on the acquisition costs for larger-scale systems. Another technical challenge is the low critical point of $CO_2$, requiring either an adaptation of the conventional vapour compression cycle to work with transcritical $CO_2$ or a cascade system. The latter can be a solution for both the above problems. A secondary upstream refrigeration system pre-cools the air for the $CO_2$-loaded condensor, thereby keeping the pressures low and the $CO_2$ away from its critical point. That design is typical for low-temperature refrigeration cycles (e.g. chest freezers in supermarkets).

## 3.2 Hydrofluoroolefins (HFOs)

Unsaturated HFCs, commonly referred to as HFOs, are synthetic refrigerants that have no ODP and, contrary to HCFCs and conventional HFCs, a very low GWP. The development of this fourth generation of fluorine-based refrigerant gases was driven by legislative pressure through the European MAC Directive 2006/40/EC that forbids new vehicles to use refrigerants with GWPs of over 150. Low levels of toxicity and flammability and their low GWP qualified them as the direct replacement for R134a (HFC) as the standard refrigerant for vehicular air conditioners in the EU. Due to the very similar thermodynamic properties there is no necessity for constructive changes of the air conditioning (AC) appliances. Yet, HFOs come at 10 to 15 times higher prices compared to natural refrigerants. Furthermore, the production process itself as well as the upstream fluorite mining result in additional energy consumption and negative environmental impacts.

Additionally, commonly used HFOs break down in the atmosphere and they produce four to five times more trifluoroacetic acid (TFA) than the same amount of the HFC R134a (Greenpeace, 2016). TFA and its salts have a very long lifetime and the long-term environmental impact is not predictable.

# 4 Natural refrigerants and conversion processes

When considering and planning the conversion to a new refrigerant, each situation is unique in terms of system design, installation, location and production precondition. The following sections intend to give an overview of the conversion process to natural refrigerants.

## 4.1 Conversion to natural refrigerants

Enterprises considering to convert their refrigeration systems and production lines to natural refrigerants will first evaluate the product design and production line setup. Conversion will drive design changes to both, the key components of the appliances and to the associated production line and surrounding areas.

Whether the refrigerant conversion is about domestic refrigerator, water heater, commercial cooler/freezer/vendor/dispenser, remote condensing unit or a heating ventilation and air conditioning (HVAC) system, the general approach is similar as long as the final design complies with specific technical and legal requirements of the selected natural refrigerant.

For the preparations it is highly recommended to set up a project team covering technical, procurement, finance, quality and legal aspects. This team is solely responsible for the conversion project and source agencies/experts/consultants to assist with the work.

### 4.1.1 Product type and product design

Because of the special characteristics of natural refrigerants, there is no drop-in replacement solution for the conversion from HFCs. This means that the equipment requires some redesign work on the refrigeration system. Each system needs to be analysed for its suitability to use the new refrigerant (i.e. chemical and working pressure compatibility). The necessary design changes need to be identified, not only to enable conformity to relevant standards (see also section 4.4) but also to provide additional levels of cooling and energy performance. A cost analysis of the proposed new designs and its commercial impact should be conducted. Also, the supply and availability of the new components and the commercial viability of the supply chain need to be checked.

When converting to HC refrigerants, a charge study will support the reduction of safety risks and enable the development of a technically and financially smart solution. Recommendations:

- a highly optimised heat exchanger (HX) via:
  - perfect airflow through the whole HX surface area to take the maximum available cooling capacity on the evaporator side and to eliminate the maximum system heat on the condenser side,
  - eliminate any unutilized HX sections,
  - reduce the pipes diameter by using wire-on-tube (WOT) condenser;
- reduce the accumulator size to the strict minimum (i.e. when converting from R134a to HC, the accumulator size can be reduced by two thirds);
- use of roll-bond evaporator (lower charge and less expensive);
- make a smart/balanced decision between converting to HC-R600a (isobutane) or to HC-R290 (propane) depending on the needed cooling capacity. In general, commercial equipment with an internal net volume of up to 400 litres are suitable for R600a. Bigger units will need HC-R290. This is due to the higher volumetric efficiency of R290 vs R600a;

- reducing the number of welding/brazing points will reduce the potential leak rate, hence reducing the safety risks. These reductions are attained by using 'single pipe' WOT condensers and aluminium evaporators. Both are good, reliable and inexpensive solutions.

When converting to $CO_2$, the pipes' wall thickness is a key parameter to withstand the high system working and standstill pressures (from 20 bars on the low side to 120 bars on the high side under normal operation conditions). WOT gas cooler and aluminium tube evaporators (with appropriate wall thickness) shall be used to reduce leakage and optimise costs.

- In both cases above, use the appropriate aluminium pipes' alloy, to avoid external corrosion due to ambient conditions (i.e. salty air near sea areas). The recommended aluminium alloy for refrigeration is AA3103.

There are two common chemical interactions (creating corrosion) that may occur:

- $CO_2$ with water (moister) producing carbonic acid that corrodes metals, leading to component failures (i.e. the compressor) and/or to refrigerant leakage. To avoid such accidents, and before recharging with refrigerant, the system must be flashed with either dry air or nitrogen, followed by a vacuum at 0.6 mbar for at least 10 to 15 minutes.
- Ammonia reacting/corroding copper elements. Hence, all piping is made of steel.

Table 3 below shows the critical equipment's (i.e. coolers, vending machines, heat pump, etc.) components/elements to be considered when converting equipment from HFCs refrigerant to natural ones (HCs, $CO_2$ or $NH_3$). As there is a huge number of applications, we limited the below details and table to the most common commercial applications.

There are two families of components to be considered, those that are part of the refrigeration system and the auxiliary ones:

1. Refrigeration cycle components: refrigerant, compressor, heat exchangers (condenser, evaporator, suction line, intercooler), connecting pipes, expansion device, receiver, accumulator, electrical/electronic elements such as solenoid valve, controls, thermostat, etc. The design and requirements of most of these components will be affected/changed when converting the refrigeration system from HFCs to natural refrigerants.
2. Example of auxiliary components in three different applications:
   - refrigerator/cooler: fan motors, lighting, door switch, voltage stabiliser, gas sniffers, electronic boards, displays, etc.;
   - dispenser: water agitator, water circuit, drink circuit, valves, electrical system, etc.;
   - vending machines: dispensing motors and mechanism, payment system, lighting, AC/DC transformer, etc.;
   - the major part of the above auxiliary components won't be affected by the refrigeration technology conversion. The key change is the ATEX[5] electrical elements when switching to HCs.

HCs often pose the easiest and less expensive option for converting small HFC systems to natural refrigerants. The system design of HC refrigerants requires only minimal alteration from that of synthetic refrigerants. Moreover, HCs have a very high critical temperature and the ability to reject heat up to 50% faster than fluorocarbon refrigerants, resulting in high energy efficiency for applications in high-temperature regions.

5 EU directive on eqiupment and work environment in explosive atmospheres. The abbreviation ATEX derives from the French title: 'Appareils destinés à être utilisés en **AT**mosphères **EX**plosibles'.

| Key Components for Equipment Conversion | | |
|---|---|---|
| HFCs to HCs | HFCs to $CO_2$ | HFCs to $NH_3$ |
| Compressor: either R600a or R290 compressor, depending on the application | Compressor | Compressor |
| ATEX, spark-free electrical components:<br>light bulb, light/door switch, fan motors, thermostat, transformer, electrical connections, electronic boards, displays, voltage stabiliser, gas sniffers | Heat exchangers, gas cooler, evaporator, suction line, piping: these elements shall have the appropriate wall thickness to handle the pressure requirements – 0.4 mm for a steel WOT gas cooler, 0.6 mm for a copper gas cooler of 5 mm ID, 0.8 mm for an aluminium evaporator of 6 mm ID. | Steel piping (copper can't be used due to chemical reaction with ammonia) |
| HC refrigerant: flammable, high miscibility with oil | $CO_2$ refrigerant:<br>effect on human body, i.e. dizzy/drunk feeling, ice burn in contact with the skin, heavier than air, formation of carbonic acid when mixed to water/moister, solid state at ambient conditions | $NH_3$ refrigerant: toxic, nasty odour, reaction with copper (corrosion) |
| Proper heat exchangers design to minimise the HC charge and reduce the number of welding points, see the technical details in section 4.1.1 | Proper heat exchangers design for cost reduction and leakage minimisation, see the technical details in section 4.1.1 | |

Table 3: Summary of design changes of the key components when converting from HFCs to natural refrigerants (based on collection of industry's best practice examples)

### 4.1.2 Production line/site:

Key watch-out areas when converting a production line from HFCs to natural refrigerants:

1. charging station & related components, incl. gas detection and ventilation,
2. installation of detectors, fire extinguishers, ventilation systems according to safety requirements for flammable refrigerants (HC, NH3),
3. installation of detectors, masks, eyes and body showers according to safety requirements for toxic refrigerants ($NH_3$),
4. safety features for high-pressurised refrigerant ($CO_2$): installation of high pressure hoses and valves,
5. integration of a helium pressure test and leak detection station, and
6. mounting of technologies for refrigerant storage, piping, valve station.

### 4.1.3 After-sales infrastructure

Converting to natural refrigerants not only demands the adaptation of the appliance design and production line, it will also influence the requirements of the after-sales infrastructure.

Any refrigeration system, if not properly constructed, installed, operated or maintained, can be a danger to the health and safety of persons and detrimental to the environment.

Technicians involved with working on a refrigerant circuit should hold a valid certificate from an approved training organisation. This general approach is important for the use of any refrigerants including natural refrigerants.

Steps to be undertaken by the manufacturer are the following (GIZ Proklima, 2011):

- identify, characterise and understand the current after-sales, service and maintenance infrastructure,
- identify necessary changes to the current after-sales infrastructure, including needs for training, new servicing tools, etc.,
- formalise revised after-sales infrastructure and allocate responsible person(s) for the implementation.

## 4.2 Financial impact and cost analysis

One of the barriers for conversion is the needed financial investment. Whether conversion of equipment (domestic refrigerators, freezers, commercial units, vending machines, etc.) or a production line takes place, there are some cost implications for a redesign.

The potential financial impact is largely on the capital expenditure (CAPEX) side, especially concerning the production lines in terms of investment in new equipment, e.g. charging machine. The figures in the tables 4, 5 and 6 are informative and meant to give directions. These figures vary by country (transport, taxes, import duties, components availability, etc.), by application (economy of scale), subject to local legislations, etc. The tables show the impact for the redesign of the refrigerant cycle of a refrigerator.

Apart from the needed trainings for technicians and operators, the impact on operational expenditure (OPEX, e.g. servicing and operational cost) should be virtually the same as for current HFC systems. For example, servicing a household refrigerator will not differ much whether the refrigerant is HFC or HC.

The focus on the servicing side is the competency of the service technicians and the training towards the safe handling of natural refrigerants (see section 4.5).

Conversions to natural refrigerants come under various scenarios. For example, in the EU, a legal requirement for domestic applications and more regulations will be enforced soon (2022) for larger units.

Other decisions to switch are driven by major multinational companies wanting to be more sustainable and reduce their carbon footprint. Worth mentioning is also that continuous pressure is coming from NGOs and environmental agencies.

The tables below serve as examples of the main cost impact of a conversion from HFCs/HCFCs (R22) to natural refrigerants. Table 4 considers household refrigerators and table 5 light commercial units with an internal net volume of up to 500 litres.

The numbers are conservative averages, depending on the HFC baseline design and based on real tear-down analysis and supply chain optimisation work made by major suppliers and some global end users.

| Components | Comments | Expected conversion cost to R600a per unit |
|---|---|---|
| Compressor | Bigger compressor needed (swept volume) | $10 |
| Condenser | Should be using steel wire-on-tube (WOT) | $0 |
| Evaporator | Continue using roll-bond design for the HC units | $0 |
| Fan motors | If currently using shaded pole motors, necessary to move to ATEX (spark-free) design for the HC units (considering two fans per cooler) | $10 |
| Internal light and electrical components | Must be spark-free when converting to HC | $5 |
| Refrigerant | Based on approx. cost/unit | $1 |
| Piping | | $0 |
| | **TOTAL for domestic units** | **$24** |

Table 4: Expected equipment conversion costs for household refrigerators (based on average industry and end user experiences, own research by HEAT GmbH)

| Components | Comments | Expected conversion cost (per unit) to R290 | Expected conversion cost (per unit) to $CO_2$ |
|---|---|---|---|
| Compressor | Same price as HFC when converting to R290 | $0 | $35 |
| Condenser/gas cooler | Should be using steel WOT for all refrigerants | $0 | $0 |
| Evaporator | • Move from copper/alu to alu/alu for $CO_2$ in commercial units by using appropriate aluminium alloy (AA3103)<br>• Continue using roll-bond design for the HC units in both domestic and commercial refrigerators | $0 | –$5 |
| Fan motors | If currently using shaded pole motors, necessary to move to ATEX (spark-free) design for the HC units (considering two fans per cooler) | $12 | $0 |
| Internal light and electrical components | Must be spark-free when converting to R290 | $5 | $0 |
| Refrigerant | Based on approx. cost/unit | –$2 | –$3 |
| Piping | Thicker walls required for $CO_2$ pipes | $0 | $4 |
| | **TOTAL for commercial units** | **$15** | **$31** |

Table 5: Expected equipment conversion costs of commercial refrigerators up to 500 litres internal volume (based on average industry and end user experiences, own research by HEAT GmbH)

| Production line stations | Comments | Expected conversion cost to HC (R600a and/or R290) | Expected conversion cost to $CO_2$ (commercial units) |
|---|---|---|---|
| Charging station & related components, incl. gas detection ventilation | Need for new unit & components for conversion to either HC or $CO_2$; focus on flammability for the HC systems and on high pressure for the $CO_2$ ones | $65,000 | $70,000 |
| Safety features for flammable refrigerants | Additional gas detectors, ventilation and ducting, extinguishers, spark-free electrical components, etc. | $20,000 | $0 |
| Technicians training and certification | | $4,000 | $4,000 |
| Helium pressure test and leak detection | If currently using shaded pole motors, necessary to move to ATEX (spark-free) design for the HC units (considering two fans per cooler) | $12 | $0 |
| station | No need for new equipment if it already exists for the HFC line | $100,000 | $100,000 |
| Refrigerant storage, piping, valve station, etc. | | $10,000 | $15,000 |
| | **TOTAL for production line** | **$199,000** | **$189,000** |

Table 6: Expected conversion costs of refrigerators production line, domestic and commercial (based on average industry experiences, research by HEAT GmbH)

The costs for the conversion of the related production lines of refrigerators are consolidated in table 6, as the relevant production line equipment for conversions is the same for domestic and commercial refrigerators.

The numbers are conservative estimates of the conversion costs due to investments in new line equipments (i.e. charging station, helium pressure test), trainings, etc. Any already existing equipment will reduce the total investment.

In addition to the equipment's investment costs it must be mentioned that the price for HFC refrigerants continues to rise. The HFC R404A, for example, is one of the major refrigerants in use for large commercial applications. Due to its very high GWP of 3,922, it will be banned for many applications in the EU by 2022.

Recent price developments of refrigerants in the EU show that R404A will, from an economical perspective, not be a viable solution. Major refrigerant suppliers in the UK increased the prices for high-GWP refrigerants by 25 to 30% (Cooling Post, 2017). Similar developments apply to other high-GWP refrigerants, such as R507 and R134a.

## 4.3 Risk assessment

In conclusion, natural refrigerants are environmentally safe, yet several characteristics necessitate technical adaptations concerning flammability (HC), toxicity ($NH_3$), high pressure systems ($CO_2$) and combinations of these.

The risk assessment is a sensitive area when converting to a natural refrigerant and aims to assure safety and reliability during the product life cycle. A holistic approach should consider the following areas:

- technical conception and design,
- manufacturing lines,
- transport and storage,
- installation,
- operation,
- maintenance and repair, and
- recycling and disposal.

Table 7 shows the typical characteristics of common natural refrigerants in use. The third column shows their safety classification according to the standards ISO 817 and EN 378, which influences the applicability and the appropriate safety measures of the system and its installation site.

There are three recommendations to minimise the flammability risk for explosion protection. Recommendations:

1. minimise the amount of flammable refrigerant,
2. avoid system leakage, and
3. identify and avoid potential sources of ignition.

Table 8 displays the necessary considerations and recommends possible precautions to be taken, accordingly.

| Ref. name | Ref. no. | Safety classification | Advantages | Risks |
|---|---|---|---|---|
| Ammonia | R717 | B2 | • Excellent efficiency for low temperature applications (well below 0 °C)<br>• Easy to operate and maintain<br>• Low operating pressure | • Toxic<br>• Corrosive to copper, brass and bronze<br>• Highly flammable |
| Carbon dioxide | R744 | A1 | • High temperature fluid for heat recovery<br>• Non-toxic<br>• Low maintenance systems<br>• Non-corrosive | • High discharge pressures<br>• Very low critical temp. (31 °C)<br>• More complex systems |
| Propane (HC) | R290 | A3 | • High efficiency<br>• No significant cost upcharge<br>• Availability | • Highly flammable<br>• Low charge limits (150 g) that restrict application areas |
| Propylene (HC) | R1270 | A3 | • High volumetric refrigeration capacity | • Highly flammable |
| Isobutane (HC) | R600a | A3 | • High energy efficiency | • Highly flammable |

Table 7: Natural refrigerants classification (EN 378 & ISO 817) and characteristics (Sources: international standards and industry's best practice examples, own research and compilation by HEAT GmbH)

## 4.4 Appropriate regulations and standards

In many developing countries, the lack of or inappropriate standards and regulations, as well as low public sensitivity to safety risks, pose key barriers regarding the introduction of environmentally-friendly refrigerants. But meanwhile, some governments recognise that conformity of national refrigerant, product and service quality with international best practice – as well as an effective management of differing technical characteristics of natural refrigerants with respect to their toxicity, flammability and operating pressure level – is essential to overcome safety issues. Sound technical standards and regulations are the prerequisite for establishing a functioning infrastructure. In addition, the focus will have to be laid on control and enforcement in order to meet minimum safety requirements.

Standards, guidelines and instructions can be developed by themselves if the necessary expertise, technical resources and appropriate funding can be acquired. Yet, symbiotic effects from cooperation with other A5 countries are being disregarded, and often necessary resources are missing. The adaptation of existing standards (e.g. EN 378) or parts of these can therefore pose a quicker and more cost-effective solution.

General normative references are the RAC standards that refer in part also to umbrella standards and regulations, e.g. fire protection, ATEX and pressurised equipment standards.

Main standards are the IEC 60335-2-40, IEC 60335-2-89, ISO 5149 and EN 378. The below table 8 summarises the main safety standards for A3 (HCs) refrigerants.

| Standard | Title | Application | HC charge size limits |
|---|---|---|---|
| IEC and EN 60335-2-24 | Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers | Domestic refrigeration | Up to 150 g |
| IEC and EN 60335-2-40 | Particular requirements for electrical heat pumps, air conditioners and dehumidifiers | Any air conditioning and heat pump appliances | Up to ~1 kg and ~5 kg, depending upon application |
| IEC and EN 60335-2-89 | Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor | Any refrigeration appliances used for commercial situations | Up to 150 g |
| EN 378 | Refrigeration systems and heat pumps – safety and environmental requirements | All refrigeration, air conditioning and heat pumps; domestic, commercial, industrial | Variable, depending upon application |
| ISO (DIS) 5149 | Mechanical refrigerating systems used for cooling and heating – safety requirements | All refrigeration, air conditioning and heat pumps; domestic, commercial, industrial | Variable, depending upon application |
| ASHRAE 15 | Safety standard for refrigeration systems | • Linked to building codes, mechanical and absorption refrigeration and heat pump systems used in stationary applications | • Depending upon application and room size |

Table 9: Safety standards related to A3 refrigerants, i.e. hydrocarbons (Source: own research and compilation by HEAT GmbH)[6]

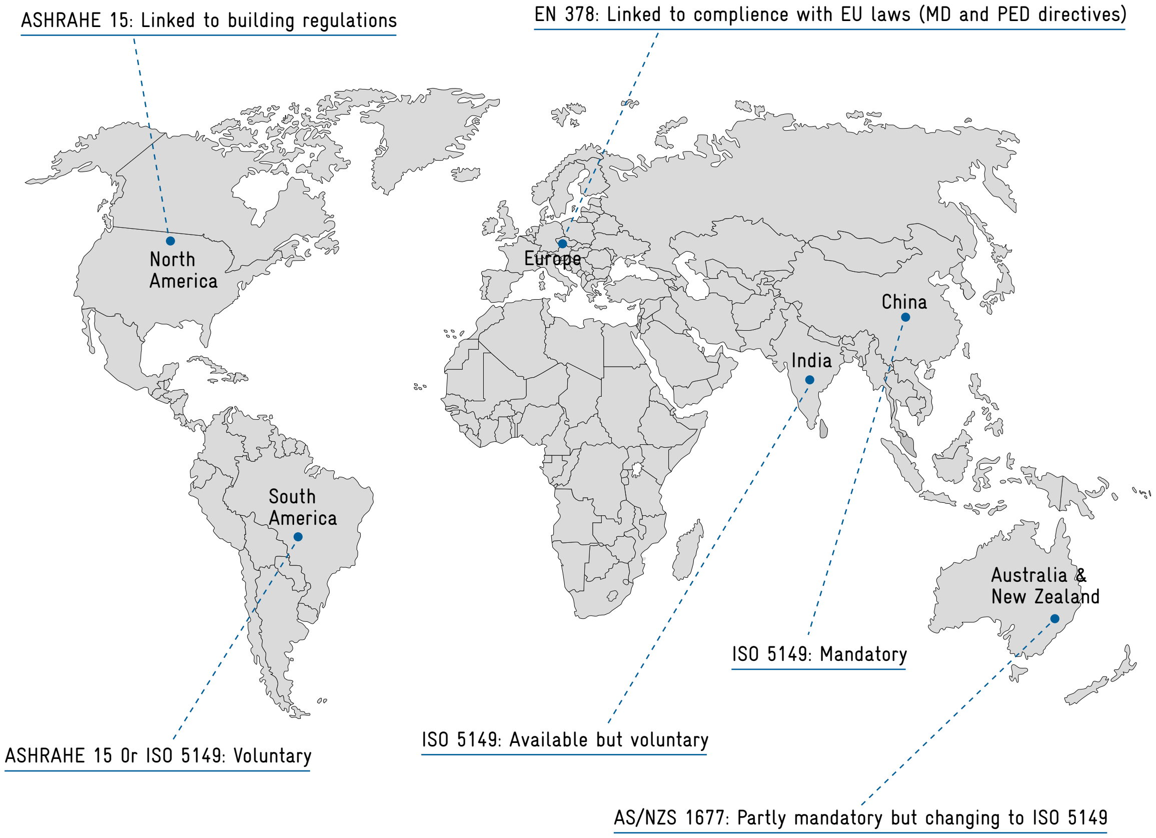


Figure 6: Global application of refrigeration standards (adapted from Danfoss, 2017)

## 4.5 Capacity building trainings

Refrigeration systems, if not properly constructed, installed, operated and maintained, can be a danger to the health and safety of persons, detrimental to the environment and negatively impacting the business. Any person who is involved with working on any refrigerant circuit must be trained accordingly.

However, in many countries, existing refrigeration systems are kept running beyond their economic lifetime, resulting in increasing demand of service, repair and energy consumption. Technicians need to develop knowledge and skills to apply best practices. Lessons learned from previously conducted activities in Europe demonstrate that improved levels of training and work methods generally greatly reduce leakage rates and the number of failures. This kind of 'investment' always pays back.

Technicians at the production line, but also for service and maintenance, need to be familiar with the main system components and equipment, covering construction, characteristics and how they are used. Staff working with the appliances and production-related machines need to be aware of the important safety concepts and safety-related issues of flammable and/or toxic substances (HC, $NH_3$) and high pressure ($CO_2$). They have to be aware of mechanical component failures, with special regard to leakage processes, gas dispersion and mixing, combustion/fire and overpressure/explosion concepts. It makes sense to involve staff early, when developing and designing the refrigeration system.

As European countries were confronted with a big discrepancy between required skills and education quality, the European Leonardo project formulated the minimum qualification of a 'Refrigeration Craftsmen'

(see below). This serves as a good example for general core trainings of technicians. Specific theoretical and practical updates for the use of flammable, toxic or high working pressure refrigeration systems include:

1. refrigerants and lubricants and their properties, with special regards to potential hazards,
2. circuit components for the use with HC/$NH_3$/$CO_2$,
3. tools and equipment for refrigerant handling,
4. accessing a refrigerant circuit,
5. refrigerant recovery and venting,
6. repair of leaks,
7. leak checking (for tightness testing),
8. strength (pressure) testing,
9. system evacuation,
10. refrigerant charging,
11. repairs to electrical components,
12. routine system checks,
13. gas detection, and
14. cylinder handling.

Main standards for the technician trainings are the following European codes:

- EN 13313:2010 – Refrigerating systems and heat pumps – Competence of personnel
- EN 50110-1:2014 – Operation of electrical installations – Part 1: General requirements (Electrically Qualified Person)
- ISO 13585-2012 – Brazing – Qualification test of brazers and brazing operators

# 5 Application

Due to international binding agreements and nationally adapted regulations, the pressure on manufacturers to produce environmentally sound refrigeration equipment rises steadily.

Table 9 displays an availability overview of refrigeration, air conditioning and heating systems using natural refrigerants. It shows the categories that are applicable and where experience has already been gained. This table is not exhaustive.

(Remark: blank field – currently no natural refrigerant alternative known to the author)

| Sector | Subsector | Equipment type | System type | HC | $NH_3$ | $CO_2$ | $H_2O$ |
|---|---|---|---|---|---|---|---|
| Refrigeration | Domestic refrigeration R744 | Domestic refrigerator | Stand-alone | X | X | | |
| | | Domestic freezers | Stand-alone | X | | | |
| | Commercial refrigeration | Display cabinets | Stand-alone | X | | X | |
| | | | Centralised | | X | X | |
| | | | Cascade | | X | X | |
| | | | Condensing units | X | | X | |
| | | | Indirect | X | | | |
| | Cold storage | Storage cabinets | Stand-alone | X | | X | |
| | | Cold stores | Cold rooms | | X | | |
| | | | Condensing units | X | | | |
| | Food processing | Process cooling/freezing | Centralised | | X | | |
| | Transport refrigeration | Refrigerated trucks | Stand-alone | X | | X | |
| | | Reefer Containers | Stand-alone | X | | | |
| | | Marine refrigeration | Stand-alone | | | X | |

| | | | | HC | $NH_3$ | $CO_2$ | $H_2O$ |
|---|---|---|---|---|---|---|---|
| Air conditioning | Domestic air conditioners, dehumidifiers | Portable units | Stand-alone | X | | | |
| | | Window units | Stand-alone | | | | |
| | | Trough-wall units | Stand-alone | X | | | |
| | | Split units | Remote | X | | | X |
| | Commercial air conditioning | Split units | Remote | X | | | |
| | | Multi-split/ VRV | Distributed | | | | |
| | | Central packaged | Remote | | | | |
| | | Positive displace chillers | Indirect | X | | | |
| | | Centrifugal chillers | Indirect | | | | |
| | Mobile air conditioning | Cars | Remote | | | X | |
| | | Buses | Remote | | | X | |
| | | Trains | Remote | | | X | |
| | | Aeroplanes | Remote | | | | |
| | | Water heaters | Stand-alone | | | X | |
| | | Central heating | Remote | | | X | |

Table 10: Availability of equipment using natural refrigerants (Source: own research and compilation by HEAT GmbH)

Very prevalent refrigerant applications for specific system types are:

- hydrocarbon R600a for small stand-alone systems for domestic and commercial refrigeration (refrigerators, water dispensers and freezers),
- propane (R290) and $CO_2$ (R744) for small to large-sized display cabinets for commercial purposes (stand-alone coolers, freezers and vending machines),
- ammonia (R717, $NH_3$) for chillers in food and beverage processing, and
- $CO_2$ for large condensing units, industrial installations and water heaters.

Even though there are many applications for natural refrigerants of all kinds, hydrocarbons often pose an easy and less expensive option for the conversion of systems from HCFC and HFC to natural refrigerants. As the physical properties like specific evaporation enthalpy and evaporation pressures are often close to those of common HCFCs or HFCs in use, usually only minor changes to the refrigerant cycle components are needed.

## 5.1 Application examples

The following application examples intend to demonstrate the applicability of conversion to natural refrigerants. The companies mentioned have already converted or intend to convert to natural refrigerants.

### 5.1.1 Conversion case study 1 – Walton in Bangladesh

#### Company profile:

Walton Ltd. is a multinational electrical, electronics, and automobiles brand with one of the largest, well-equipped R&D facilities in the world. The Walton Group headquarter is based in Bangladesh.

Walton entered the electronics business in 1994 with the manufacturing of electrical and electronic items, and gradually expanded its operations in many other fields, such as multi-stored refrigerators, freezers and air conditioners. Walton, with offices in more than 20 countries, produces 3 million refrigerators and 0.3 million air conditioners per annum.

Especially for the refrigerators, not only the refrigerant is of high importance, but also the blowing agent used in the insulation foam within the cabinet.

#### Products:

Domestic refrigerators, air conditioners and compressors


Figure 7: Condenser manufacturing at Walton manufacturing site (Source: Walton)

#### Motivation for conversion:

The conversion of the products and production lines supports Bangladesh in meeting the provisions of the Montreal Protocol. The conversion of the foam blowing agent HCFC-141b took place under the HCFC Phase Out Management Plan (HPMP).

The objective of the currently ongoing conversion project at Walton is to phase out HFCs from the refrigeration system, replace these HFCs by hydrocarbons, i.e. natural refrigerants, and thereby additionally contribute to Bangladesh's obligations under the Kigali Amendment.

#### Conversion details:

**Initial refrigerants:** HCFC-141b, HCFC-22, HFC-134a

**New refrigerants:** cyclopentane, R600a (isobutane)

The full conversion at Walton is divided in two phases, covering 1) the foam blowing agent conversion from R141b to cyclopentane, and 2) the refrigerant conversion from R22 and R134a to HC (R600a).

By November 2013, the complete phase-out of 501 tons of R141b from the insulation foam process was achieved.

Figure 8 below shows Walton's increased consumption (2007–2012), followed by the rapid phase-out (2012–2014) of the blowing agent R141b. The phase-out of 501 tons of R141b equals a concurrent phase-out of 300.6 metric tons of $CO_2$ equivalent.

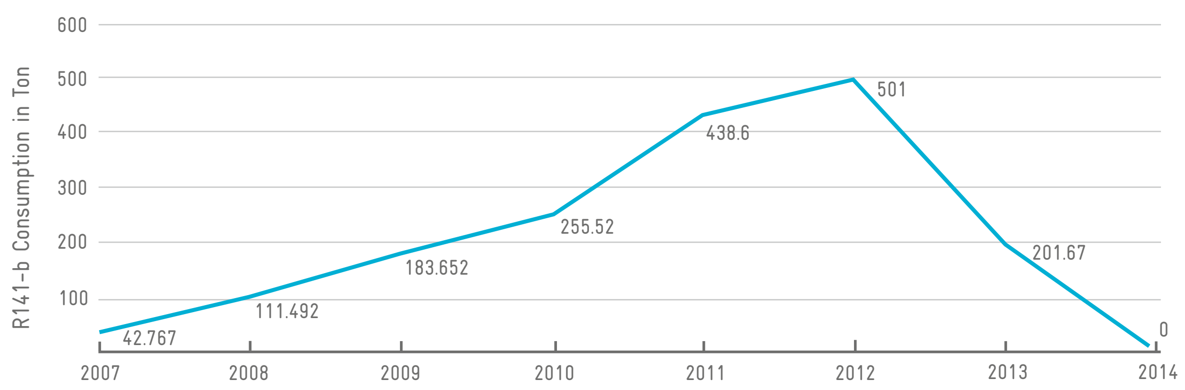


Figure 8: Walton's R141b consumption in the years 2007–2014 (adapted from: Walton)

Phase 2 is still in progress: a 30% reduction (89 tons) of R134a refrigerant from the refrigerator production was achieved by November 2014. This reduction is equivalent to the elimination of 115.7 metric tons of $CO_2$ equivalent.

Ongoing projects and timelines for phase 2:

- 100% phase-out of R134a: December 2018,
- 100% phase-out of R22: December 2019,
- introduction of HC inverter compressor (variable speed compressor): December 2019.

### Conversion steps:

1. finalisation of the plant layout, the product redesign and implementation:
   a. **plant layout modification:** including a Quantitative Risk Assessment (QRA, prepared by TÜV SÜD), a hazard identification, an accident frequency analysis, the consequence modelling risk analysis and risk simulation;
   b. **production line modification:** introducing an isobutane-compatible gas charging pump, the gas supply from a central gas storage and a gas alarm and monitoring system. The exhaust of the gases is ensured by a ventilation system at the gas charging and repairing area. Changing of the assembly line motor to explosion-proof and ensuring to keep distance of any flame in 10 metres from the gas charging area;
   c. **product design modifications:** separate the electric connection from the evaporator or use explosion-proof electric parts;
2. retrofitting of existing foam dispensers and foaming fixtures,
3. new equipment and systems, such as cyclopentane and isobutane storage and handling system, premixing station and water conditioning system,
4. installation, trials commissioning and safety audit,
5. manufacturing operation, and
6. after-sales.

### Conversion challenges faced by Walton:

- isobutane system needs bigger space inside the production area for safety reasons,
- shipment and transportation of highly flammable refrigerant involves risk factors in developing countries,
- higher costs, but lack of funding, searching for a grant to meet safety standardisation and implementation, and
- longer time required for product redesigning process.


Figure 9: Isobutane storage at Walton manufacturing site (Source: Walton)

### 5.1.2 Conversion case study 2 – Palfridge Ltd. T/A The Fridge Factory in Swaziland

**Company profile:**

Palfridge Ltd. T/A The Fridge Factory was founded in 2001. Palfridge is based in Matsapha/Swaziland in Southern Africa. It is the leading refrigerator manufacturer in the country. Based in the centre of the country, Palfridge employs around 650 people. It manufactures household refrigerators and commercial refrigerators, such as bottle coolers and chest freezers.

**Products:**

Commercial and household refrigerators

Figure 10: View on leak testing and evacuation area (front) and foaming area (back) at Palfridge (Source: Palfridge)

### Motivation for conversion:

The reasons considered for the conversion at Palfridge were mainly that hydrocarbons are more energy-efficient compared to the synthetic refrigerants used before. This yields lower electrical expenses and a better OPEX. Despite this, the environmental impact of hydrocarbons is negligible compared to the former refrigerants, as they have zero ODP and low GWP. Further reasons for the conversion were low noise levels of the refrigerators and the lower vibration. Finally, the company image and market expectations for cleaner products have motivated Palfridge, as the units are sold globally. Additionally, the conversion was incident to cost savings due to the lower refrigerant charge and smaller heat exchangers. The conversion of the foam blowing agent was furthermore motivated by increasing problems of importing the substance, as the ODS HCFC-141b was banned by the government. Altogether, the conversion to natural refrigerants creates a win-win-situation for Palfridge.

### Conversion details:

**Initial refrigerants:** HCFC-141b, HCFC-22, HFC-134a

**New refrigerants:** HCs cyclopentane, R600a (isobutane) and R290 (propane)

The commercial refrigerators were using HCFC-22 and the domestic refrigerators HFC-134a, the foam blowing agent was HCFC-141b in both cases.

The conversion at Palfridge was applied in two phases: 1) the phase-out of HCFC-22 and HFC-134a as refrigerants, and 2) the phase-out of HCFC-141b as foam blowing agent.

The conversion of the foam blowing agent started in the year 2012 for the three main foaming machines of the factory. The finalisation of the conversion (remaining door-foaming machine) took place in the year 2015.

### Conversion steps:

1. Redesign of refrigerators:
   The main standard that was employed for the appliances redesign is IEC 60335-2-89. However, where charge sizes exceeded 150 g, the European standard EN 378 was followed.
2. Production line modifications:
   Nearly the entire production line was changed, including:
   - new tightness testing equipment, evacuation lines, charging equipment and performance testing areas,
   - adequate labelling and fire-fighting equipment introduced in the factory, and
   - installation of gas alarm monitoring and ventilation systems for the production line.
3. After-sales training and marketing work:
   - technicians received training in both production and after-sales servicing; these trainings were conducted by equipment suppliers and contractors,
   - customer awareness raising in the region to accept HCs.
   - implementation of trainings for low skilled technicians through national authority Swaziland Environment Authority (SEA) – the national ozone unit (NOU).

### Conversion challenges faced by Palfridge:

One of the main barriers was the time taken to analyse and redesign each cabinet model. In addition, HC was widely unknown in the country and not available locally. Palfridge had to find a supplier importing HCs, which included the suppliers acquiring additional tanks with the U.S. Department of Transport (DOT) rating.

Another barrier was changing the culture of the workforce. The staff had to understand the safety issues and obey the documented standards, especially in the maintenance team.

### The main conversion barriers were:

1. customer fear; lack of understanding,
2. initial higher equipment costs and maintenance,
3. lead time for spare parts delivery, and
4. units with old gas still being imported by the competitors.

Figure 11: Refrigerant charging area at Palfridge manufacturing site (Source: Palfridge)

### 5.1.3 Conversion case study 3 – Transfrig Ltd. in South Africa

#### Company profile:

Transfrig, founded in 1980, is the leading African developer, manufacturer and supplier of transport refrigeration systems (TRS). Transfrig delivers their equipment primarily to their home market in South Africa but also to the sub-Saharan region, as well as East and West Africa. It is planned to expand into other regions in the near future.

Transfrigs TRS comprise direct driven equipment for small to medium-sized applications (vans, small trucks; Koolvan), diesel-electric systems for cooling trucks, dual temperature systems (both direct and diesel electric), and indirect cooling systems with eutectic plates (Kooltube). Transfrig additionally offers a cryogenic system using liquid nitrogen (LN2).

#### Product:

Transport refrigeration systems

#### Motivation for conversion:

Transfrig's goal is to continually evolve in the pursuit of excellence in transport refrigeration equipment technology and advancement to the benefit of their clients. Their aim is to make transport refrigeration more sustainable and to improve on the food cold chain.

#### Conversion details:

**Initial refrigerants:** HFC-404A, HFC-134a

**New refrigerant:** R290 (propane)

For the production of the TRS, the consumption of HFC-134a is about 300 kg per year and of HFC-404A about 4,100 metric tons per year. The major products in terms of sales are diesel-electric systems. The company has four production lines.

First steps towards conversion were undertaken in a bilateral project called 'Green Transport Refrigeration' under the German International Climate Initiative, funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in the years 2012 to 2017, when one of the main product designs, the MT450, was converted to use R290. The R290-prototype is still tested in a field trial.

## Planned conversion steps:

- redesign and production of all (relevant) transport refrigeration products to use R290 and to have higher efficiency than current models,
- conversion and improvement of production line,
- provision of suitable training to technicians and other related staff, and
- implementation of quality/safety system for market surveillance.

The redesign of TRS and larger systems is more complicated than the conversion of refrigerators. The main considerations during design adjustments were:

1. **Charge size reduction:**

   The original refrigerant charge of the MT450 is about 3.5 kg. When R290 is charged directly into the baseline system, approximately 1.5–2.0 kg is required. Through redesign of heat exchangers and other system components, substantial reduction of refrigerant charge was achieved.

   The result is a charge size of 0.62 kg for the prototype MT480.

2. **Elimination of sources of ignition (SOI) and safety area classification:**

   - Heat exchanger fan motors should be brushless type. Ignition risks posed by engine air intake or sparks on the starter motor are mitigated through pre-purge of the fans.
   - The electrical panel contains a large number of contactors, relays and other components that could act as a SOI, so it is necessary to ensure that in the event of a leak a concentration exceeding 50% of the lower flammable limit (LFL) cannot occur.
   - Although some potential SOIs inside the refrigerated space, such as light switch, truck engine air intake, etc., it was demonstrated that leaks will not result in a flammable mixture which could extend to those parts.

## The main conversion barriers are:

1. zero experience in HCs handling,
2. untrained technicians in the field,
3. customer fear; lack of understanding, and
4. higher equipment initial costs and maintenance.


Figure 12 and 13: Transfrig truck with propane refrigeration unit MT80i (Source: Transfrig)

Despite those difficulties a very positive balance can be drawn after one year field trials with MT480 under real working conditions.

For the properly trained technicians there was not much difference in handling compared to other conventional TRS.

Trouble-free operation and highest efficiency of the system make Transfrig confident that the slightly higher initial investment for the operators will be more than compensated in savings throughout the lifetime.

Due to the improved coefficient of performance (COP) – efficiency and the extremely low GWP of R290, the system also contributes in large scale to climate protection.

## 5.2 Potential systems for conversions

The following examples pose potential systems for the conversion to natural refrigerants.

### 5.2.1 Solar refrigerators – Sundanzer

Solar direct driven refrigerators pose a very sustainable cooling solution for off-grid areas. The project is financially supported by Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). Using the sun's energy to provide the cooling – avoiding the use of batteries – makes the solar direct driven refrigerator a very sustainable device.

**Product:**
Solar direct driven refrigerator

**Initial refrigerant:** HFC-134a

**Potential alternative refrigerant:** R600a

**Potential steps of a conversion:**
The conversion to hydrocarbon R600a requires only small adjustments to the appliance itself:

- adaptation of product design to the use of R600a:
  - change of DC compressor to R600a compressor,
  - sizing of capillary tube towards R600a,
  - possibly adjustment of electrical components close to the refrigerant cycle;
- labelling of refrigerator that it contains flammable refrigerant.

The main focus of the production line conversion will be on:

- refrigerant (HC) charging area and machines. (only machines with approval from a reputable certification body are acceptable; the machine details and test reports must be checked and verified).

Figure 14: Solar direct driven refrigerator (Source: Sundanzer)

### 5.2.2 Milk cooling system – Promethean

Promethean Power Systems designs and manufactures refrigeration systems for cold storage and milk cooling applications in off-grid and partially electrified areas of developing countries. The project is financially supported by PAEGC. The equipment for cold chain supply networks can be operated without diesel generators. The technology is based on a thermal energy storage system that effectively eliminates diesel generators in rural refrigeration applications.

#### Product:

Milk cooling system

| | |
|---|---|
| **Initial refrigerant:** | HFC-404A |
| **Potential alternative refrigerant:** | R290 |

#### Potential steps of a conversion:

The conversion of a large system like the milk cooling system to hydrocarbons (in this case R290) requires a deep product redesign work of the refrigeration system.

The main focus of the redesign work will be on:

- refrigerant charge size reduction,
- improvement of leak tightness,
- a risk assessment towards the elimination of SOIs,
- safety area classification and adaptation of components,
- replacing the R404A compressor by an R290 compressor, and
- reducing diameters of condenser and evaporator tubes.

Very important will be the training of after-sales servicing technicians and the familiarising of anyone working with the system.

The installation of the system plays an important role in terms of safety (and also allowable refrigerant charge). Only persons with knowledge of the refrigeration system should have access to the refrigerant containing parts of the system.

Figure 15: Milk cooling system by Promethean (Source: Promethean Power)

# 6 Conclusion and recommendations

Driven by regulatory developments concerning F-gases with high global warming potentials (GWP), the global market for refrigeration and air conditioning equipment is undergoing major changes. Not only from an environmental, but also from an economic perspective, it is conceivable that high-GWP refrigerants, such as HFCs, are not a viable long-term solution. Taking into account the fast development of F-gas regulations around the world as described in chapter 2 and the drastic price development of synthetic refrigerants, the safest opportunity to avoid a drawback in the market is to convert to natural refrigerants early.

Natural refrigerants pose a future-proof solution, as they show no ozone depleting potential and a negligible GWP. They are not patented and often produced as a by-product of other processes. For this reason natural refrigerants are available at lower prices in comparison to synthetic refrigerants. Their very good environmental and technical performance has been proven in the field by multiple manufacturers and drove many end users to adopt them. These conversions were motivated not only by the positive impact on ozone and climate protection, but also by economic considerations, especially in terms of lower refrigerant prices and better energy performance, leading to savings on the electricity bills. In Europe, for example, higher energy performance facts (e.g. on energy labels) have been used for decades as a marketing tool to trigger the widespread market introduction of energy-efficient cooling technologies using natural refigerants, e.g. for domestic and light commercial applications.

Whilst the benefits of natural refrigerants are widely recognised, the chemical industry continues to promote synthetic HFC-substitutes, such as HFOs. Chemically, HFOs are a form of HFCs, but due to their negative impact, the new class of chemicals is being sold under a different name (Greenpeace, 2016). This is misleading to consumers, as although HFOs have a lower GWP than previous HFCs, their extraction poses a considerable environmental threat. Moreover, in cormparison to natural refrigerants, the processes required to produce HFOs are very complex and expensive.

This guide introduced the latest trends in the refrigeration sector and the various reasons to switch to green technologies based on natural refrigerants early, ahead of the binding requirements set out in the HFC phase-down targets of the Montreal Protocol. Natural refrigerants have the potential to replace synthetic refrigerants in almost all domestic and commercial applications. They are already available in many markets for the different refrigeration and air conditioning subsectors.

Challenges are mainly related to the properties of natural refrigerants, namely the flammability of hydrocarbons, the toxicity of ammonia as well as the high operating pressure for $CO_2$ and the associated technical, financial and legal implications. To successfully manage these, the paper provided practical adivse in chapter 4. More general recommendations are in particular related to:

1. **Decision-making:** Set up a project team responsible for the conversion project, covering all technical, procurement, financial, quality and legal aspects as described above. The overall objective of the team will be to answer the core question: which refrigerant is the most appropriate solution for my product and/or process, considering the targeted audiences to be addressed in the market? One of the first tasks in this respect will be to evaluate the product design and production line setup. The team will calculate investments, meeting safety risks, and prioritise the best available solution. All aspects of manufacturing, system-relevant items (such as pipes for high pressure components and avoidance of occurring flammable mixtures) as well as maintenance and

repair must be taken into account. Additionally, the availability of natural refrigerants – in sufficient quantities – must be evaluated (details are demonstrated in chapter 4).

2. Funding: In developing countries, sufficient financial support for the introduction of an environmentally-friendly alternative can be acquired from international funding bodies. As one example, the Multilateral Fund under the Montreal Protocol supports low-GWP conversion projects in developing countries. Since 1991, the Fund has approved activities including industrial conversion, technical assistance, training and capacity building worth over US$3.6 billion. However, also domestic finance (e.g. incentive programmes) can play an important role.

3. **Regulations & policies:** Businesses willing to convert will lobby for the improvement of framework conditions. A top-down and/or bottom-up approach can be introduced by governments to support conversion processes. Promoted solutions are governmental sanctions on the use and acquisition of chemical refrigerants (top-down, as with the EU F-gas policy), eco-labelling schemes for cooling appliances and/or reward schemes by which consumers receive subsidies when buying green cooling appliances (bottom-up, as with the Japanese F-gas policy). The most effective regulations will vary on a country-by-country basis.

4. **Training, availability & capacity building:** Adequate training for involved staff and technicians to manufacture, install and maintain green cooling technologies is crucial, as natural refrigerants require higher safety standards due to increased levels of toxicity, pressure and flammability. Standards such as EN 13313 and ISO 13585-2012 require the necessary competences and should be implemented.

5. **Raising awareness & marketing:** This encompasses informing end users about the importance and relevance of the given solution as 'state of the art'. This might also include component suppliers, transport and other services. It will be extremely important for the overall success to convice stakeholders (and 'educate' consumers) about their choices when buying cooling appliances, as well as addressing any safety concerns they may have regarding natural refrigerants.

In chapter 5 selected case studies from the refrigeration sector clearly showed that the conversion to natural refrigerants is a desideratum and a manageable task.

On a global scale, the transition to global natural refrigerants does not only contribute to the ambitious climate goals of different international treaties such as the Paris Agreement to the UNFCCC and the Kigali Amendment to the Montreal Protocol, but also brings about socio-economic benefits. For example, introducing green cooling technologies can support the achievement of numerous Sustainable Development Goals (SDGs) set forward by the United Nations as illustrated in the figure below.

**1 No Poverty** – RAC&F sector transformation involves creation and formalization of jobs, enhancing the source of income. Energy-efficient appliances also lessen electricity costs and make recources available for other needs.

**2 Zero hunger** – Reliable RAC&F systems improve the quality of cold chains that preserve food and beverages. This increases productivity and access to quality food and nutrition, hence contributing to enhanced food security.

**3 Good health and Well-being** – A sustainable and reliable RAC&F sector provides cold chains that ensure the quality and shelf life of food items and medical goods, even in remote areas.

**4 Quality education** – Capacity building activities such as training and further qualification of technicians as well as with the relevant policymakers are central to a substainable RAC&F sector transformation.

**7 Affordable and Clean Energy** – Substainable RAC&F solutions focus on innovative, energy-efficient technologies and encourage the use of renewable energy recources.

**8 Decent Work and Economic Growth** – The substainable introduction of climate-friendly RAC&F technologies involves the creation and formalization of jobs as well as strengthening local capacities and infrastructure for production.

**9 Innovation and Infrastructure** – One advantage of using natural refrigerant based technologies and products is that there are no intellectual property rights and less patents associated with them compared to synthetic substances.

**11 Sustainable Cities and Commitments** – RAC&F technologies such as air-conditioning and building insulation improve human living environments. Promoting long-term solutions in the sector also encourages the shift towards a circular economy

**12 Responsible Consumption** – Natural refrigerants have zero ODP and a negligible GWP; they are part of natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere.

**13 Climate Action** – A RAC&F sector based on low-GWP refrigerants and energy-efficient systems minimizes the negative impacts of the sector on the climate while proving for the growing demand for cooling applications.

**17 Partnerships for the Goals** – RAC&F sector transformation relies strongly on the involvement of both the public and the private sector as well as multi-stakeholder partnerships.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) supports the Sustainable Development Goals.

Figure 16: Relevance of a green cooling sector for the Sustainable Development Goals (GIZ Proklima, 2016)

# Annex A
# Further standards

### Generally applicable standards:

- DIS ISO 5149 – Mechanical refrigerating systems used for cooling and heating – Safety requirements
- IEC 60335-2 – Specification for safety of household and similar electrical appliances (and its various subparts on the specific application)
- ISO 817 – Refrigerants – designation and system classification
- EN 378 – Refrigerating systems and heat pumps – Safety and environmental requirements
- EN 15834 – Refrigerating systems and heat pumps – Qualification of tightness of components and joints
- EN 1012-1 – Compressors and vacuum pumps. Safety requirements. Compressors
- EN 1012-2 – Compressors and vacuum pumps. Safety requirements. Vacuum pumps
- EN 12178 – Refrigerating systems and heat pumps. Liquid level indicating devices. Requirements, testing & marking
- EN 12263 – Refrigerating systems and heat pumps. Safety switching devices for limiting the pressure. Requirements and tests
- EN 12284 – Refrigerating systems and heat pumps. Valves. Requirements, testing and marking
- EN 12693 – Refrigerating systems and heat pumps. Safety and environmental requirements. Positive displacement refrigerant compressors

### Pressure-related standards:

Remark: all systems using a refrigerant cycle (refrigeration, air conditioning, heat pumps) are pressurised systems.

- ISO 4126 – Safety devices for protection against excessive pressure
- ISO 4126-2 – Safety devices for protection against excessive pressure. Bursting disc safety devices
- EN 13136 – Refrigerating systems and heat pumps. Pressure relief valves and their associated piping. Methods for calculation
- EN 14276-1 – Pressure equipment for refrigerating systems and heat pumps. Vessels. General requirements
- EN 14276-2 – Pressure equipment for refrigerating systems and heat pumps. Piping. General requirements

### Explosive atmospheres – especially significant for the use of hydrocarbons:

- EN 1127-1 – Explosive atmospheres – explosion prevention and protection. Basic concepts and methodology
- EN 13463-1 – Non-electrical equipment for use in potentially explosive atmospheres. Part 1: Basic method and requirements
- EN 13463-5 – Non-electrical equipment for use in potentially explosive atmospheres. Part 5: Protection by constructional safety
- EN 13463-6 – Non-electrical equipment for use in potentially explosive atmospheres. Part 6: Protection by control of ignition source
- EN 14797 – Explosion venting devices
- EN 14986 – Design of fans working in potentially explosive atmospheres
- EN 15198 – Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres

### Training and competence of personnel:

- EN 13313 – Refrigeration systems and heat pumps. Competence of personnel
- ISO 13585:2012 – Brazing – Qualification test of brazers and brazing operator

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn

Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de

On behalf of

Federal Ministry
for Economic Cooperation
and Development